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Effect of slope position on physico-chemical properties of eroded soil

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Abstract

The research work was conducted on eroded soil (Missa Series) in Samarbagh, District Lower Dir to determine the effect of slope position on soil physico-chemical properties. Soil samples were collected from top-slope, mid-slope and bottom slope positions at horizon-A, B and C. Results showed a significant difference among the physico-chemical properties of top, mid and bottom slope soils. Bulk density of the top-slope (1.51 g cm^{-3}) was the highest followed by mid (1.39 g cm^{-3}) and bottom slopes (1.32 g cm^{-3}). Conversely, electrical conductivity EC-2.47 dS m^{-1}), phosphorus (3.40 mg kg^{-1}), Potassium (118.8 mg kg^{-1}), Organic matter content (1.52 %), clay content (20.39 %) and silt content (49.17%) were the highest at bottom slope followed by mid and top-slopes, respectively. Soil A, B and C horizons were also significantly ($p<0.05$) different in their physico-chemical properties. Mean values showed that horizon Ap had the highest bulk density (1.43 g cm^{-3}) and lower electrical conductivity (1.74 dS m^{-1}), phosphorus (2.29 mg kg^{-1}), potassium (84.86 mg kg^{-1}), organic matter (1.08%), clay (12.83%) and silt content (40.49%) than both the B and C horizons. The deterioration in physico-chemical properties of top slope as compared to mid and bottom slopes and that of Ap horizon as compared to B and C horizons were presumed to be due to past soil erosion effect that removed the finer soil particles including soil organic matter and other plant nutrients. This study concluded that increasing extent of erosion due to slope effect can further deteriorate soil properties. The control of such damaging effects would require soil conservation strategies such as proper land levelling, afforestation, terracing and inclusion of restorative crops in cropping systems on these lands.

Key words: Water erosion, nutrient deficiencies, soil series, eroded soil

Introduction

Soil is an important natural resource for growing plants, food and fiber. The suitability of soil for crop production is based on the quality of the soil's physical, chemical and biological properties. One of the naturally occurring processes that affect detrimentally these soil properties and subsequent crop production is soil erosion. Slope is one of the important factors of universal soil loss equation. Its geometry, such as slope angle, length and curvature influence runoff, drainage, and soil erosion (Aandahl, 1948) causing a significant difference in soil physico-chemical properties (Brubaker *et al*., 1993). Erosion would normally be expected to increase with increase in slope length and slope steepness, as a result of respective increase in velocity and volume of surface runoff. The relation between slope and erosion can be expressed by the equation; $E \alpha \tan^{-m} \Theta L^{-n}$ (Zingg, 1940) where E = soil loss per unit area, Θ is slope angle and L is slope length. The universal soil loss equation relates erosion to slope steepness as in the equation $S= 0.065 + 0.045\ S + 0.0065\ S^2$ (Wischmeier and Smith, 1978). The relationship indicates that land erosion will increase by about 20 fold as slope increases from 2 to 20%. Changere and Lal (1997) reported that the highest biomass production, greater nutrient uptake and highest maize grain yield were observed in the lower slope position i.e. 37 % and 57 % more than the upper and middle land slope position respectively. Nejad and Nejad (1997) reported the effect of topography on soil genesis and development of soils and observed that slope gradient and slope length had direct and indirect effect on calcification, mineralization and soil physical and chemical properties. Lucot *et al*. (1998) reported that spatially of caesium-137 contamination was related to slope, vegetation type and humus thickness.

In the area under study, water erosion takes place in which slope steepness is the dominant factor where the accumulating water removes the finer soil particles including soil organic matter and plant nutrients thus adversely affecting the soil physico-chemical properties and crop productivity. The study aimed to investigate the effect of slope position on physico-chemical properties of soil in order to provide the basic information about the fertility status of the eroded land of the area. Such information

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would be helpful in recommending the type and amount of fertilizer and other soil management practices in future crop production strategies on such soils.

Material and Methods

The study was conducted on eroded soil (Missa series) in Samarbagh, District Dir Lower. Four different locations viz.Qala Kamabat, Chamaktali, Shontala and Badin were selected where a pit of 1 m^2 was dug at the top, mid and bottom slope positions up to the depth of C horizon. Both core and disturbed soil samples from all the three horizons i.e A, B and C horizons were collected with three replications (three pits within the same site considered as replications) and were analyzed for the soil properties (Table 1).

Table 1: Some physico-chemical characteristic of the composite soil samples collected at (0-20 cm) depth from the four locations

Location	BD (g cm^{-3})	pH	EC (dS m^{-1})	OM (%)	Texture
Qala Kambat	1.47	7.9	1.77	0.97	Silt Loam
Chamaktalai	1.37	8.1	1.90	1.05	Silt Loam
Shontala	1.44	7.8	2.03	1.20	Silt Loam
Badin	1.43	7.8	1.90	1,09	Silt Loam

Table 2: Mean values of soil physico-chemical properties of Missa soil series

Soil Horizon	Slope Position			Mean	LSD (0.05)
	Top-Slope (5-6%)	Mid-Slope (2-3%)	Bottom-Slope (Normal)		
		Bulk Density (g cm^{-3})			
Ap	1.43	1.32	1.29	1.34b	
B	1.53	1.40	1.38	1.44a	0.047
C	1.57	1.44	1.28	1.43a	
Mean	1.51a	1.39b	1.32c		
LSD(0.05)		0.063			
		Soil pH			
Ap	8.00	7.63	8.15	7.93b	
B	8.13	8.25	8.23	8.20a	0.233
C	8.05	8.18	8.38	8.20a	
Mean	8.06	8.02	8.25		
LSD (0.05)		ns			
		EC (dS m^{-1})			
Ap	1.10	1.77	2.35	1.74b	
B	1.05	1.83	2.47	1.78b	0.066
C	1.17	1.92	2.60	1.90a	
Mean	1.11c	1.84b	2.47a		
LSD (0.05)		0.126			

Means followed by same letters are not significantly different at probability level $p < 0.05$

The air dried, crushed and sieved (2 mm) soil samples were analyzed for different physico-chemical properties using standard procedures as; soil texture (Tagar and Bhatti, 1996), bulk density (Blake and Hartage, 1984), electrical conductivity (Rhoads, 1996), organic matter (Nelson and Sommers, 1982), pH (Mclean, 1982) and AB-DTPA extractable P and K (Soltanpour and Schwab, 1997). Data thus collected was statistically analyzed using RCBD with two factorial split plot design (Steel and Torrie, 1980).

Results

Bulk density

Results indicated a significant ($p<0.05$) effect of slope position on soil bulk density (Table 2). The mean bulk density of top-slope position was the highest (1.51 g cm^{-3}) which was 9 and 14% higher over the mid (1.39 g cm^{-3}) and bottom (1.32 g cm^{-3}) slope positions, respectively. It was further observed that the bulk density in the Ap horizon (1.34 g cm^{-3}) was significantly ($p<0.05$) lower (7%) than the bulk density both in B (1.44 g cm^{-3}) and C (1.43 g cm^{-3}) horizons (Table 2).

Soil pH

Soil pH did not show significant variation down the slope (Table 3). However, bottom slope had the highest pH

(8.25) which was 2 and 3% higher than top and mid-slope positions, respectively. However, this difference was statistically non-significant. Data, further, indicated that soil pH was the lowest in Ap horizon (7.93) which increased in the B and C horizons down the soil profile, significantly ($p<0.05$).

Electrical conductivity (EC)

Slope position had a significant ($p<0.05$) effect on soil electrical conductivity (EC) (Table 2). Bottom slope had the highest EC (2.47 dS m^{-1}) followed by mid slope (1.84) and top slope (1.11). The EC values of bottom slope were about two fold higher than the mid and top-slope positions, respectively. It was further observed that soil EC increased significantly ($p<0.05$) from Ap (1.74 dS m^{-1}) and B horizons (1.78 dS m^{-1}) to C horizon (1.90 dS m^{-1}) down the soil profile and this increase of EC in C horizon over Ap and B horizons was 8 and 7%, respectively.

AB-DTPA extractable Phosphorus

Results showed that slope position had a significant ($p<0.05$) effect on extractable phosphorus (P) and the bottom slope had the highest extractable P (3.40 mg kg^{-1}) followed by mid slope (2.96 mg kg^{-1}) and top slope (2.16 mg kg^{-1}) positions, respectively (Table 3). The increase in extractable P at bottom slope was 15 and 57% higher than the mid and top slopes positions, respectively. It was, further, noted that extractable P in the three soil horizons (Ap, B and C) down the profile was also significantly ($p<0.05$) different (Table 3) and was found the highest in B-horizon (3.14 mg kg^{-1}) which was 37% higher than the Ap and 2% higher than the C horizon.

AB-DTPA extractable Potassium (K)

AB-DTPA extractable Potassium (K) was significantly ($p<0.05$) different at different slope positions down the slope (Table 3). The bottom slope had the highest K (118.8 mg kg^{-1}) which was 13 and 54% higher than the mid and top slope positions, respectively. Similarly, extractable K in different soil horizons (A, B, and C) down the slope profile also differed significantly ($p<0.05$) (Table 3). The B horizon had the hoghest extractable K (109.41 mg kg^{-1}) which was 2 and 29% higher than the C and Ap horizons, respectively.

Table 3: Mean values of soil physico-chemical properties in Missa soil series

Soil Horizon	Slope Position			Mean	LSD (0.05)
	Top-Slope (5-6%)	Mid-Slope (2-3%)	Bottom-Slope (Normal)		
		AB-DTPA extractable phosphorus (mg kg^{-1})			
Ap	1.39	2.23	3.26	2.29b	
B	2.50	3.28	3.65	3.14a	0.228
C	2.61	3.38	3.29	3.09a	
Mean	2.16c	2.96b	3.40a		
LSD(0.05)		0.268			
		AB-DTPA extractable potassium (mg kg^{-1})			
Ap	56.78	82.70	115.10	84.86b	
B	90.75	114.53	122.95	109.41a	6.52
C	84.45	118.70	118.53	107.23a	
Mean	77.3c	105.3b	118.8a		
LSD (0.05)		4.82			
		Soil organic matter (%)			
Ap	0.68	0.99	1.56	1.08b	
B	1.03	1.25	1.60	1.29a	0.15
C	1.06	1.42	1.41	1.29a	
Mean	0.92c	1.22b	1.52a		
LSD (0.05)		0.21			

Means followed by same letters are not significantly different at probability level $p<0.05$

Soil organic matter

Soil organic matter (OM) was significantly ($p<0.05$) affected by different slope positions (Table 3) and the bottom slope position had the highest soil OM content (1.52 %) followed by mid and bottom slope position. The bottom slope position had 25 and 65% higher OM than the mid and top-slope positions, respectively. Data (Table 3) further showed that soil OM content in different soil horizons (Ap, B and C) also differed significantly ($p<0.05$). The highest soil OM content was found in the B and C horizons (1.29% each) which was 19% higher than the Ap horizon.

Soil clay content

Soil clay content was significantly ($p<0.05$) different at different slope positions down the slope (Table 4). The maximum soil clay content (20.39 %) was observed at the bottom slope which was 18% higher than the mid slope and almost two fold higher the bottom slope positions. Clay content in different soil horizons (Ap, B and C) was also significantly ($p<0.05$) different being the maximum clay content (17.15%) in C horizon which was 34% higher than the Ap horizon but was alike the B horizon.

Table 4: Mean values of soil separates (clay, silt and sand) in Missa soil series

Soil Horizon	Slope Position			Mean	LSD (0.05)
	Top-Slope (5-6%)	Mid-Slope (2-3%)	Bottom-Slope (Normal)		
		Soil clay content (%)			
Ap	6.18	11.57	20.75	12.83b	
B	10.80	19.65	20.83	17.09a	0.82
C	11.45	20.40	19.60	17.15a	
Mean	9.48c	17.21b	20.39a		
LSD (0.05)		1.21			
		Soil silt content (%)			
Ap	31.33	40.58	49.55	40.49b	
B	41.10	50.20	49.30	46.87a	0.90
C	40.50	49.35	48.67	46.17a	
Mean	37.64c	46.71b	49.17a		
LSD (0.05)		1.72			
		Soil sand content (%)			
Ap	62.50	47.85	29.70	46.68a	
B	48.10	30.15	29.88	36.04b	1.09
C	48.05	30.25	31.72	36.67b	
Mean	52.88a	36.08b	30.43c		
LSD (0.05)		2.18			

Means followed by same letters are not significantly different at probability level $P<0.05$

Soil silt content

Slope positions (top, mid and bottom) showed a significant ($p<0.05$) difference in the silt content (Table 4). Bottom slope had the highest silt content (49.17 %) while top slope had the lowest (37.64%) values. Silt content at bottom slope position was 5 and 35% higher than the mid and top slope positions, respectively. It was, further, observed that silt content in different soil horizons (Ap, B and C) was also differed significantly ($p<0.05$) and the maximum silt content (46.87%) was found in the B horizon which was 16% higher than the Ap horizon and 1.5% higher than the C horizon.

Soil sand content

Effect of slope positions (top, mid and bottom) on soil sand content was significant ($p<0.05$) (Table 4). Top slope position had the highest sand content (52.88 %) followed by the mid slope (36.08%) while the bottom position had the lowest (30.43%) sand content. Sand content at top slope was 47 and 74% higher than the mid and bottom slope positions, respectively. It was further, noted (Table 4) that sand content in Ap horizons (46.68%) was significantly ($p<0.05$) higher than the sand content in the B (36.04%) and C (36.67%) horizons but the sand content in the B and C horizons was statistically at par. Thus, Ap horizon had 30 and 27% higher sand content than the B and C horizons, respectively.

Discussion

Data showed that soil bulk density had a decreasing trend down slope and an increasing trend down the profile both of which are presumed to be due to soil erosion processes. Looking the data regarding sand, silt and clay content, it was observed that the clay and silt content showed an increasing trend while sand content showed a decreasing trend down the slope. Thus it was clear from the data that the soil bulk density had an inverse relationship with soil clay and silt content and had a direct relationship with sand content. Actually, when soil erosion takes place, finer particles get suspended in the accumulating water and are transported down the slope thus leaving coarser material at the top slope positions with less micro pore spaces and higher soil bulk density. Conversely, the suspended finer particles are transported down the slope where they accumulate at the bottom thus increasing the clay and silt content at the bottom slope positions with higher micro porosity and lower bulk density. In the case of severe sheet erosion at top slope positions, almost all of the Ap horizon is washed away thus exposing the dense loess material in the B and C horizons to the surface parts of which become Ap horizon where structural developments are usually inadequate. These results are supported by Midkiff *et al.*, (1985). Similarly, during the erosion processes, the suspended clay particles also leach down the profile along with percolating water and accumulate there in the B and C horizons thus clogging the existing soil pores and increasing soil bulk density down the profile. The lower soil bulk density at the Ap horizon might also be due to the cultural practices on the Ap horizon which frequently loosen the soil surface thus increasing soil porosity and decreasing the bulk density of soil. The results are in line with the work of previous researchers (Shafiq *et al*., 1988 and Brady, 1984) who reported that loose and porous top soil have low bulk densities than the compact subsoil.

Data regarding soil pH showed a non-significant effect of slope position on soil pH, yet the increase in soil pH at the bottom slope position could be attributed to the accumulation of bases that were presumed to have been eroded from the top and bottom slope positions as is evident from the work of Garcia *et al.* (1990) who reported highest Na+ concentration at bottom slop position of 30 eroded sites. Hendershot *et al*. (1992) also reported slightly higher pH at the down slope postions. Similarly, the increase in soil pH down the profile could be attributed to the downward movement of ca and accumulation therein the B and C horizons. Previous researches also reported a sharp increase in soil pH with increasing soil depth (Webb and Dowling, 1990, Khan *et al*., 2004) due to higher accumulation of Ca^{2+} in the sub-surface soil (Kaihura *et al*., 1999). Hao and Chang (2003) reported similar results and revealed that in irrigated soils Ca^{2+} decreased in surface soil (0-15 cm) but increased at depths below 30 cm due to the downward movement of lime with peculating water to sub-surface soil that cause an increase in soil pH.

Data showed an increasing trend in soil EC down the slop as well as down the profile. Along with suspended clay in accumulating water soluble cations and anions also move down the slope with surface runoff and accumulate there at the bottom slope which might have caused an increase in EC at the down slope positions. That is why the erosion process depletes soil productivity by changing the concentration of salts in the root zone. Similarly, such soluble cations and anions also percolate down the soil profile along with percolating water thereby increasing the EC in the B and C horizons as compared to the surface soil. The work of other researchers (Putman and Alt., 1987, Ahmad and Khan, 2009) also confirmed the increase in EC with depth which they have presumed to be due to the downward movement of soluble ions (Na^+, K^+, Mg^{2+} Cl^-, HCO_3^-) with percolating water during the erosion processes and its accumulation in the compact subsoil.

Results regarding AB-DTPA extractable P, K and soil organic matter revealed an increasing trend from top to bottom slope position which might be due to their downward movement with runoff water from top slope and accumulation there at the bottom slope postion. Even then, being eroded soils (Missa series), the concentration of all the three important soil fertility parameters were below their optimum range (P<4.0 mg kg^{-1}, K<120 mg kg^{-1} and OM<2%) at all three slope positions. Previous researchers (Pruess *et al*., 1992) argued that the amount of soil organic matter in the semi-arid region is the main factor of controlling P and other soil fertility parameters. Thus decrease in soil organic matter content at top slope (and vice versa) with erosion hazards might have decreased the available P and K in soil at top slope position. The lower content of AB-DTPA extractable P, K and soil OM in Ap horizon as compared to B and C horizon might be due to the decreasing width of Ap horizon with uniform sheet erosion and its subsequent intermixing with sub-soil by tillage implements which might have brought parts of comparatively non-fertile sub-soil to the surface thus making it a part of Ap horizon. The comparatively higher content of the AB-DTPA extractable P and K in B horizon over C horizon might also be due to the downward movement of dissolved P, K and organic carbon with percolating water and thereby their accumulation in the B horizon. With the increase in organic matter in soil, microbial activity in soil might have increased which in turn might have enhanced the decomposition process and release of P, K, Ca, Mg and micronutrients (Bullock, 1992).

Conclusion

Our work confirmed that detrimental effects of soil erosion are higher at top slope as compared to mid and bottom slope thereby changing the soluble salts and mineral nutrient concentration in the root zone thus affecting soil productivity. The deterioration in physico-chemical properties of top slope as compared to mid and bottom slopes and that of Ap horizon as compared to B and C horizons were presumed to be due to past soil erosion effect that removed the finer soil particles including soil organic matter and other plant nutrients. Special attention may be given to top slope position to control such damaging effects for its soil fertility restoration which would require soil conservations strategies such as proper land levelling, afforestation, terracing and inclusion of restorative crops in cropping systems on these lands.

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